RESULTS OF 1-D LOCATION CALIBRATION STUDIES RELATED TO THE TERRITORY OF NORTHERN EURASIA

Victor V. Kirichenko and Yury A. Kraev
Western Services Corporation
Under subcontract to
Science Applications International Corporation

Sponsored by The Defense Threat Reduction Agency

Contract No. DSWA01-98-C-0029

ABSTRACT

During the last three years, new regional travel-time tables for different geotectonic provinces of Northern Eurasia were developed in the framework of the Russian Seismoacoustic Research for Comprehensive Nuclear-Test-Ban Treaty (CTBT) Monitoring project. One of the main objectives of the project is to calibrate travel times for regional seismic waves travelling to the seismic stations of the Russian Academy of Sciences included in the International Monitoring System (IMS).

The territory of Northern Eurasia was initially subdivided into 13 provinces based on the results of the analysis of Pn travel times as well as taking into account recently published papers on seismic and tectonic regionalization of Northern Eurasia. We presented newly developed travel-time tables for different geotectonic provinces at the 21st and 22nd Seismic Research Symposiums. Upon completion the effort on collection and analysis of travel-time data for 13 studied provinces, we came to the conclusion that the territory of Northern Eurasia may be subdivided as follows: only three large geotectonic provinces for Pn and Sn phases (platform areas, paleozoic massifs and young platform as well as tectonically active regions); only two provinces for Pg phase and the only province for Lg phase. We present the recent regionalization of Northern Eurasia for our 1-D location calibration studies as well as newly constructed travel-time tables and their comparison with the IASPEI-91 tables. Also, source-specific station corrections (SSSCs) for the stations of the RAS included in the IMS are presented as well as their comparison with SSSCs developed by other research groups.

In the framework of our project performance we review recently published and historical data on peaceful nuclear explosions (PNE) in the former USSR. In the result we concluded that ISC location estimates for the number of PNEs are subjects of large (from about 20 km to 40 km and even more) errors. Details of our analyses are presented.

The newly constructed travel-time tables as well as their modeling errors were used for tests on re-location of the underground nuclear explosions in the former Soviet Union. A comparison between the mislocation estimates for the newly constructed travel-time tables, the IASPEI-91 travel-time tables and the ISC results is presented. We conclude that the newly developed 1-D regional travel-time tables are an effective tool to be used for seismic source location in Northern Eurasia.

KEY WORDS: seismic regional characterization, location calibration.

OBJECTIVE

This work presents the results of the three year effort on the development of regional travel-time tables for different geotectonic provinces of Northern Eurasia. The overall objective is to calibrate travel times for regional seismic waves travelling to the seismic stations of the Russian Academy of Sciences included in the IMS. The newly developed travel-time tables may be directly used to improve seismic event location as well as to test and to validate 3-D travel-time models currently being developed. This project is being performed by SAIC and its subcontractors: the Western Services Corporation, the Geophysical Survey (GS) of the Russian Academy of Sciences (RAS) and the Complex Seismological Expedition (CSE) of the United Institute of Physics of the Earth (UIPE) of the RAS.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **OCT 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Results of 1-D Location Calibration Studies Related To The Territory Of Northern Eurasia**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Western Services Corporation,7196 Crestwood Blvd # 300,Frederick,MD,21703**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Proceedings of the 23rd Seismic Research Review: Worldwide Monitoring of Nuclear Explosions held in Jackson Hole, WY on 2-5 of October, 2001. U.S. Government or Federal Rights

14. ABSTRACT
See Report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

RESEARCH ACCOMPLISHED

Calibration Events

At the final stage of the generalized travel-time tables development we used only underground nuclear explosions with precisely known origin times and locations. This set of explosions includes peaceful nuclear explosions conducted in the former USSR (Sultanov et al, 1999), underground nuclear explosions at the Semipalatinsk Test Site (Bocharov et al, 1989) as well as on Amchitka Island (Springer et al, 1971 and Springer et al, 1975).

Data on Travel Times

Data resources were formed on the basis of seismic observations conducted during the time framework of 1965 - 1990 by the GS of the RAS and the CSE of the UIPE of the RAS. Values of arrival times for major regional seismic phases (Pn/P, Pg, Sn/S and Lg) were measured, analyzed and collected. The total number of the GS's stations used for the purposes of seismic calibration is about 300. The total number of the CSE's stations used for the purposes of seismic calibration is about 200. Data of seismic observations of the RAS's institutions was added by the data of about 300 station in Northern Eurasia providing data to the International Seismological Center.

Regionalization

The regionalization of Northern Eurasia was carried out on the basis of recent neotectonics, geodynamics and seismicity studies (Seismicity and Seismic Zoning of Northern Eurasia, 1995; Grachev (2000)) as well as taking into account the results of our analysis of Pn/Sn travel times. Finally, the territory of the Northern Eurasia was subdivided into 13 provinces: Central-East-European territory, Timan and Pechora Plate, Scythian and Turanian Plates, Cenozoic folded regions, Ural folded region, West-Siberian platform, Kazakh massif, Altai and Sayan region, Siberian platform, Baikal rift zone, Amur and Maritime territory, North East territory, Chukot Peninsula and Kamchatka-Kuril-Sakhalin region. The polygon vertices for the specific provinces are presented in Table 1. The upper part of the Figure 1 presents the aforementioned regionalization of the territory of Northern Eurasia.

Results

The regional travel-time curves were constructed using linear regression of the experimental travel time data using one or two linear regressions for the residual standard deviation minimization. Modeling errors were calculated as standard deviations of the experimental data from the estimated lines in a 2-degree moving window with a 50 % overlap.

The basic equation and the parameters of the developed travel-time tables are presented in the Table 2. Upon completion the effort on construction and analysis of newly developed travel-time tables for 13 studied provinces, we concluded (based on the geological and tectonic features of the studied provinces as well as statistical tests) that the territory of Northern Eurasia may be subdivided as follows: only three large geotectonic provinces for Pn and Sn phases ((1)platform areas, (2) paleozoic massifs and young platform as well as (3) tectonically active regions); only two provinces for Pg phase and the only province for Lg phase (see the below part of the Figure 1). The polygon vertices for the generalized provinces of Northern Eurasia are presented in Table 3. The parameters of the generalized travel-time tables are presented in the Table 4 and appropriate modeling errors are presented in the Table 5.
The SSSCs for the stations of the Russian Academy of Sciences included to the IMS were calculated based on Bondar’s approach (Xioping Yang et al, 1998). The Table 6 presents a comparison based on IASPEI-91 and SSSCs travel-time residuals for the IMS stations of the RAS. The improvement is obvious.

Tests on Relocation

We have located 44 historical PNEs in the former USSR with published ground truth origin times and locations (Sultanov et al, 1999) using the IASPEI-91 travel-time tables. Then, we relocated the aforementioned set of the explosions using the newly developed travel-time tables for the generalized provinces. To support our relocation tests the SSSCs were calculated for about 50 surrogate stations.

Relocation results for the aforementioned set of PNEs are presented in the Table 7 and may be summarized as follows:

- 84% of events moved closer to the GT epicenters with an average improvement of 8.4 km and a median improvement of 7.3 km;
- 82% of events moved closer to the GT epicenters by 20% or more with an average improvement of 8.3 km and median improvement of 7.2 km;
- 16% of events moved away from GT epicenters with an average deterioration of 6.3 km and a median deterioration of 5.4 km;
- 14% of events moved away to the GT epicenters by 20% or more with an average deterioration of 5.7 km and median deterioration of 4.9 km;
- average mislocations by using the IASPEI-91 tables and the SSSCs are 26.6 km and 8.6 km, respectively;
- median mislocations by using the IASPEI-91 tables and the SSSCs are 23.3 km and 7.3 km, respectively;
- 27% of GT epicenters are within the calculated 90% uncertainty ellipses by using the IASPEI-91 tables and 89% of GT epicenters are within the calculated 90% uncertainty ellipses by using the SSSCs;
- average uncertainty ellipse area is 861 km^2 for the IASPEI-91 tables and 547 km^2 for the SSSCs;
- median uncertainty ellipse area is 673 km^2 for the IASPEI-91 tables and 458 km^2 for the SSSCs;
- average and median decrease of 90% uncertainty ellipse size is 314 km^2 and 458 km^2, respectively;
- average bias in origin time estimation is 3.0 sec with an associated standard deviation of 1.6 sec for the IASPEI-91 tables and -0.2 sec with an associated standard deviation of 0.8 sec for the SSSCs.

CONCLUSIONS AND RECOMMENDATIONS

1. New regional travel-time tables for the different geotectonic provinces of the Northern Eurasia were developed and compared with the IASPEI-91 tables. The developed regional travel-time tables differ substantially from the IASPEI-91 travel-time tables. It was shown that the variety of geotectonic provinces may be presented for location calibration studies by the three extended provinces for Pn/Sn phases, by two provinces for Pg phase and the only province for Lg phase.
2. Validation testing for the set of 44 peaceful nuclear explosions conducted in the former USSR shows that estimates of event locations and time origins are significantly improved and location error ellipses are substantially reduced using the newly developed regional travel-time tables.
3. The developed regional travel-time tables are an effective tool to be used for seismic sources location at the territory of Northern Eurasia despite the fact of their one-dimensional origin.

ACKNOWLEDGEMENTS

The authors would like gratefully to thank Dr. Gerald Kent of SAIC for the overall program management, Dr. Oleg Starovoit of the GS RAS and Prof. Yury Kopnichev of the CSE of the UIPE of the RAS and their staff for providing data on travel times, computing support and fruitful discussions of research results.

REFERENCES

Bocharov, V.S., S.A. Zelentsov and V.N. Mikhailov, Characteristics of 92 Underground Nuclear Explosions at the Semipalatinsk Test Site, Atomnaya Energiya, 87, 3, 210-214 (in Russian).

Grachev A.F., Editor (2000), Neotectonics, Geodynamics and Seismicity of Northern Eurasia, Moscow, PROBEL Publishing House, United Institute of Physics of the Earth of the RAS, Fedynsky Center of Regional Geophysical and Geoecological Researches GEON of the Ministry of Natural Resources of Russia (in Russian).

Seismicity and Seismic Zoning of Northern Eurasia (1995), 2-3, Moscow, United Institute of Physics of the Earth of the RAS (in Russian).

Springer, D.L. and R.L. Kinnaman (1971), Seismic Source Summary for U.S. Underground Nuclear Explosions, 1961-1970, Bull. Seism. Soc. Am., 61, 1073-1098.

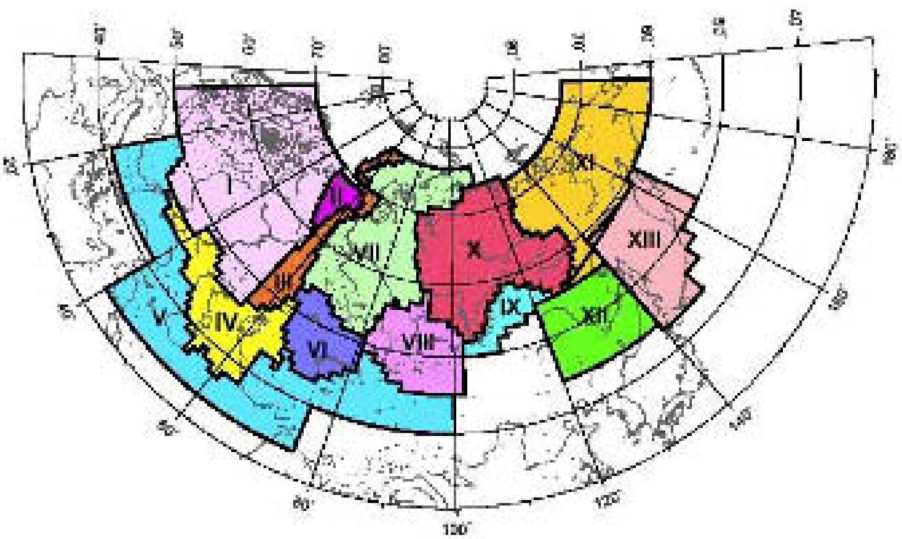
Springer, D.L. and R.L. Kinnaman (1975), Seismic Source Summary for U.S. Underground Nuclear Explosions, 1971-1973, Bull. Seism. Soc. Am., 65, 343-349.

Sultanov, D.D., J.R. Murphy, and Kh.D. Rubinstein (1999), A Seismic Source Summary for Soviet Peaceful Nuclear Explosions, Bull. Seism. Soc. Am., 89, 3, 640-647.

Xioping Yang, Keith McLaughlin, Robert North, SSSCs for Regional Phases at IMS Stations in North America and Fennoscandia, Technical Report CMR-98/46.

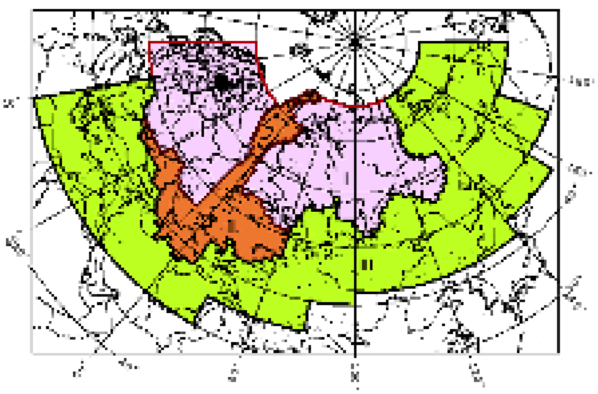
Table 1. Regionalization of Northern Eurasia

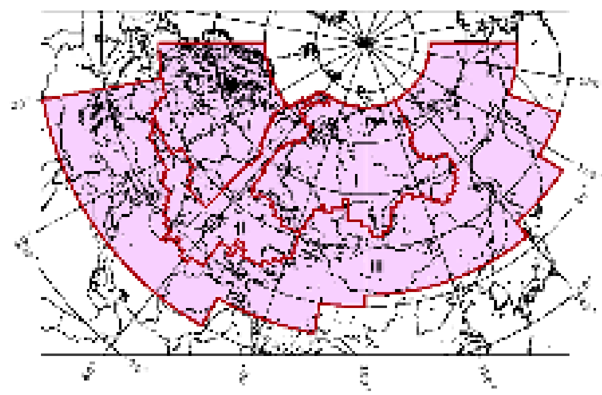
No.	Region Name	Polygon Vertices, Lat. (deg. N)-Long. (deg. E)
I	Central-East-European territory	70-48 67-48 67-49 66-49 66-50 65-50 65-51 64-52 63-52 63-53 62-53 62-54 61-54 61-56 60-57 57-57 57-56 46-56 46-49 47-49 47-47 48-46 49-46 49-40 47-40 47-27 48-27 08-26 49-26 49-25 50-25 50-10
II	Timan-Pechora Plate	69-48 69-62 68-62 68-64 67-64 67-63 66-63 66-59 65-59 65-58 63-58 63-57 60-57 60-56 61-56 61-54 62-54 62-53 63-53 63-52 64-52 64-51 65-51 65-50 66-50 66-49 67-49 67-48
III	Ural folded region	77-58 77-69 76-69 76-66 75-66 75-61 74-61 74-58 73-58 73-57 72-57 72-56 71-56 71-61 70-61 70-68 67-68 67-67 66-67 66-64 65-64 65-62 64-62 64-61 58-61 58-62 54-62 54-63 51-63 51-62 49-62 49-61 48-61 48-59 47-59 47-56 57-56 57-57 63-57 63-58 65-58 65-59 66-59 66-63 67-63 67-64 68-64 68-62 69-62 69-58 70-58 70-54 71-54 71-52 73-52 73-54 74-54 74-55 75-55 75-56 76-56 76-58
IV	Scythian and Turanian Plates	51-62 51-65 47-65 47-66 46-66 46-67 44-67 44-68 42-68 42-67 43-67 43-64 38-64 38-61 37-61 37-59 38-59 38-57 39-57 39-56 38-56 38-55 37-55 37-54 39-54 39-52 40-52 40-50 41-50 41-49 42-49 42-48 43-48 43-44 44-44 44-43 45-43 45-33 46-33 46-30 47-30 47-40 49-40 49-46 48-46 48-47 47-47 47-49 46-49 46-56 47-56 47-59 48-59 48-61 49-61 49-62
V	Cenozoic folded regions (Carpathians, Crimea, Caucasus, Kopet-Dagh, Tien-Shan)	50-20 50-25 49-25 49-26 48-26 48-27 47-27 47-30 46-30 46-33 45-33 45-43 44-43 44-44 43-44 43-48 42-48 42-49 41-49 41-50 40-50 40-52 39-52 39-54 37-54 37-55 38-55 38-56 39-56 39-57 38-57 38-59 37-59 37-61 38-61 38-64 43-64 43-67 42-67 42-68 44-68 44-67 45-67 45-69 44-69 44-70 43-70 43-75 44-75 44-77 45-77 45-79 46-79 46-81 49-81 49-84 48-84 48-86 47-86 47-87 46-87 46-90 45-90 45-100 40-100 40-76 34-76 34-40 41-40 41-20
VI	Kazakh massif	53-63 53-65 54-65 54-70 53-70 53-72 52-72 52-75 51-75 51-81 46-81 46-79 45-79 45-77 44-77 44-75 43-75 43-70 44-70 44-69 45-69 45-67 46-67 46-66 47-66 47-65 51-65 51-63
VII	West-Siberian platform	77-69 77-113 74-113 74-106 73-106 73-105 72-105 72-101 71-101 71-90 70-90 70-86 67-86 67-87 66-87 66-88 63-88 63-89 62-89 62-90 60-90 60-91 59-91 59-92 57-92 57-89 56-89 56-86 57-86 57-85 56-85 56-83 54-83 54-82 52-82 52-81 51-81 51-75 52-75 52-72 53-72 53-70 54-70 54-65 53-65 53-63 54-63 54-62 58-62 58-61 64-61 64-62 65-62 65-64 66-64 66-67 67-67 67-68 70-68 70-61 71-61 71-56 72-56 72-57 73-57 73-58 74-58 74-61 75-61 75-66 76-66 76-69
VIII	Altai and Sayan region	59-92 59-94 55-94 55-99 54-99 54-101 53-101 53-102 43-102 45-90 46-90 46-87 47-87 47-86 48-86 48-84 49-84 49-81 52-81 52-82 54-82 54-83 56-83 56-85 57-85 57-86 56-86 56-89 57-89 57-92
IX	Baikal rift zone	52-102 52-105 53-105 53-107 54-107 54-108 56-108 56-109 57-109 57-111 58-111 58-113 59-113 59-117 58-117 58-121 57-121 57-123 56-123 56-125 55-125 55-120 54-120 54-117 53-117 53-112 52-112 52-110 50-110 50-102
X	Siberian platform	74-106 74-127 69-127 69-125 68-125 68-124 67-124 67-125 65-125 64-127 64-130 63-130 63-136 59-136 59-134 58-134 58-133 57-133 57-131 56-131 56-128 55-128 55-125 56-123 57-123 57-121 58-121 58-117 59-117 59-113 58-111 57-111 57-109 56-109 56-108 54-108 54-107 53-105 52-105 52-102 53-102 53-101 54-101 54-99 55-99 55-94 59-94 59-91 60-91 60-90 62-90 62-89 63-89 63-88 66-88 66-87 67-87 67-86 70-86 70-90 71-90 71-101 72-101 72-105 73-105 73-106
XI	North East territory and Chukot Peninsula	73-127 73-170W 60-170W 60-160 59-160 59-140 55-140 55-128 59-160 59-140 55-140 55-128 56-128 56-131 57-131 57-133 58-133 58-134 59-134 59-136 63-136 63-130 64-130 64-127 65-127 65-125 67-125 67-124 68-124 68-125 69-125 69-127
XII	Amur and Maritime territory	55-120 55-140 44-140 44-120
XIII	Kamchatka-Kuril-Sakhalin region	59-160 60-160 60-164 50-164 50-157 48-157 48-154 46-154 46-150 43-150 43-140



Pn, Sn

Lg





Pg

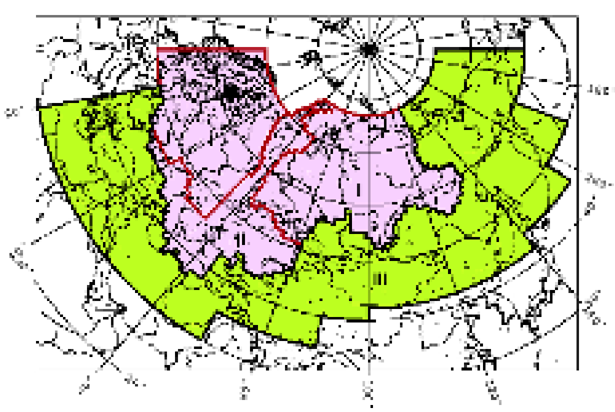


Figure 1. Regionalization of Northern Eurasia.

Table 2. Parameters of the Developed Travel-Time Curves (Depth = 0 km)
Basic Equation: $T-R/V_{red} = (A \pm \sigma_A) - (B \pm \sigma_B) \times R$

Phase	Range, km	V_{red}, km/sec	A	σ_A	B	σ_B	N	r	SD, sec
I. Central-East-European territory									
Pn	220-1100	8.0	7.78	0.36	0.0040	0.0004	43	0.83	0.7
	1101-2200	8.0	13.24	0.60	0.0089	0.0004	108	0.92	1.1
Sn	220-2200	4.62	14.86	1.88	0.0046	0.0018	50	0.34	3.1
Pg	220-1400	6.0	0.88	0.87	0.0066	0.0010	29	0.80	1.5
Lg	220-2200	3.5	2.86	2.42	0.0077	0.0021	167	0.13	5.0
II. Timan-Pechora Plate, IV. Scythian and Turanian Plates									
Pn	200-2000	8.0	8.26	0.69	0.0042	0.0011	29	0.58	0.9
Sn	350-1400	4.62	16.08	1.47	0.0031	0.0020	20	0.35	2.0
Pg	350-1000	6.0	-1.16	2.31	0.0044	0.0034	17	0.31	2.6
Lg	350-1500	3.5	3.20	2.23	0.0085	0.0030	23	0.52	3.4
III. Ural folded region									
Pn	300-2000	8.0	8.89	0.36	0.0047	0.0003	33	0.95	0.7
Sn	300-2000	4.62	12.54	1.90	-0.0006	0.0015	30	0.08	3.2
Pg	300-1200	6.0	1.13	2.80	0.0074	0.0030	14	0.57	2.8
Lg	300-2000	3.5	-2.80	3.16	0.0026	0.0025	20	0.24	4.8
V. Cenozoic folded regions									
Pn	200-990	8.0	8.20	0.41	0.0018	0.0006	91	0.32	1.2
	991-2000	8.0	10.88	0.88	0.0048	0.0006	51	0.75	1.1
Sn	200-2000	4.62	14.19	0.82	0.0001	0.0009	51	0.01	2.1
Pg	200-1100	6.0	0.77	1.04	0.0039	0.0014	29	0.49	1.4
Lg	220-2200	3.5	2.86	2.42	0.0077	0.0021	167	0.13	5.0
VI. Kazakh massif									
Pn	200-1800	8.0	9.42	0.22	0.0050	0.0002	64	0.94	0.7
Sn	200-1800	4.62	15.10	0.82	0.0029	0.0008	51	0.47	2.3
Pg	300-1200	6.0	1.13	2.80	0.0074	0.0030	14	0.57	2.8
Lg	300-2000	3.5	-2.80	3.16	0.0026	0.0025	20	0.24	4.8
VII. West-Siberian platform									
Pn	220-2200	8.0	8.22	0.22	0.0061	0.0002	70	0.90	1.3
Sn	220-2200	4.62	12.82	1.47	0.0021	0.0010	56	0.28	3.5
Pg	250-1200	6.0	1.26	2.17	0.0083	0.0022	22	0.64	2.4
Lg	220-2200	3.5	-2.96	2.77	0.0038	0.0018	44	0.30	6.3
VIII. Altai and Sayan region									
Pn	200-2200	8.0	8.71	0.24	0.0021	0.0002	113	0.66	1.0
Sn	220-2200	4.62	14.85	0.72	-0.0017	0.0006	47	0.35	2.0
Pg	200-1200	6.0	0.54	1.03	0.0038	0.0012	36	0.47	1.7
Lg	200-2200	3.5	-2.52	1.12	0.0011	0.0009	57	0.16	3.4
IX. Baikal rift zone, XII. Amur and Maritime territory									
Pn	200-2000	8.0	7.01	0.27	0.0011	0.0003	44	0.56	0.9
Sn	200-2000	4.62	12.26	0.90	-0.0032	0.0009	33	0.54	2.7
Pg	200-1200	6.0	-0.88	0.77	0.0030	0.0010	28	0.50	1.5
Lg	200-2200	3.5	-1.18	0.79	0.0016	0.0006	41	0.34	2.6
X. Siberian platform									
Pn	220-999	8.0	7.75	0.74	0.0043	0.0010	33	0.62	1.1
	1000-2200	8.0	10.89	0.69	0.0074	0.0004	80	0.90	1.3
Sn	200-2000	4.62	15.78	1.11	0.0057	0.0007	91	0.63	3.3
Pg	200-1100	6.0	-1.80	1.36	0.0035	0.0015	39	0.36	2.3
Lg	220-2200	3.5	-4.57	1.28	0.0002	0.0008	82	0.01	4.1
XI. North East territory and Chukot Peninsula									
Pn	220-1900	8.0	7.57	0.51	0.0020	0.0004	26	0.68	0.9
Sn	220-2000	4.62	11.17	1.73	-0.0033	0.0013	18	0.54	3.2
Pg	200-1200	6.0	-0.76	1.77	0.0020	0.0024	7	0.35	1.9
Lg	200-2200	3.5	-0.71	2.09	0.0018	0.0013	21	0.29	4.3
XIII. Kamchatka-Kuril-Sakhalin									
Pn	200-1800	8.0	6.99	0.51	0.0015	0.0004	43	0.47	1.0
Sn	220-2000	4.62	17.89	2.96	0.0010	0.0021	21	0.10	3.3

Note: **T - travel time, sec; R - epicentral distance, km; V_{red} - reduction velocity, km/sec; N - data set; r – correlation coefficient; SD - residual standard deviation, sec.**

Table 3. Generalized Regionalization of Northern Eurasia

No.	Region Name	Polygon Vertices, Lat. (deg. N) – Long. (deg. E)
I	Platform areas	70-10 70-48 67-48 67-49 66-49 66-50 65-50 65-51 64-51 64-52 63-52 63-53 62-53 62-54 61-54 61-56 60-56 60-57 57-57 57-56 46-56 46-49 47-49 47-47 48-47 48-46 49-46 49-40 47-40 47-27 48-27 48-26 49-26 49-25 50-25 50-10 77-69 77-127 69-127 69-125 68-125 68-124 67-124 67-125 65-125 65-127 64-127 64-130 63-130 63-136 59-136 59-134 58-134 56-123 57-123 57-121 58-121 58-117 59-117 59-113 58-113 58-111 57-111 57-109 56-109 56-108 54-108 54-107 53-107 53-105 52-105 52-102 53-102 53-101 54-101 54-99 55-99 55-94 59-94 59-92 57-92 57-89 56-89 56-86 57-86 57-85 56-85 56-83 54-83 54-82 52-82 52-81 51-81 51-75 52-75 52-72 53-72 53-70 54-70 54-65 53-65 53-63 54-63 54-62 58-62 58-61 64-61 64-62 65-62 65-64 66-64 66-67 67-67 67-68 70-68 70-61 71-61 71-56 72-56 72-57 73-57 73-58 74-58 74-61 75-61 75-66 76-66 76-69
II	Paleozoic massifs and young plates	77-58 77-69 76-69 76-66 75-66 75-61 74-61 74-58 73-58 73-57 72-57 72-56 71-56 71-61 70-61 70-68 67-68 67-67 66-67 66-64 65-64 65-62 64-62 64-61 58-61 58-62 54-62 54-63 53-63 53-65 54-65 54-70 53-70 53-72 52-72 52-75 51-75 51-81 46-81 46-79 45-79 45-77 44-77 44-75 43-75 43-70 44-70 44-69 45-69 45-67 44-67 44-68 42-68 42-67 43-67 43-64 38-64 38-61 37-61 37-59 38-59 38-57 39-57 39-56 38-56 38-55 37-55 37-54 39-54 39-52 40-52 40-50 41-50 41-49 42-49 42-48 43-48 43-44 44-44 44-43 45-43 45-33 46-33 46-30 47-30 47-40 49-40 49-46 48-46 48-47 47-47 47-49 46-49 46-56 57-56 57-57 60-57 60-56 61-56 61-54 62-54 62-53 63-53 63-52 64-52 64-51 65-51 65-50 66-50 66-49 67-49 67-48 70-48 70-51 72-51 72-52 73-52 73-54 74-54 74-55 75-55 75-56 76-56 76-58
III	Tectonic active regions	77-127 77-170W 60-170W 60-170 50-170 50-157 45-157 45-140 42-140 42-100 40-100 40-90 35-90 35-70 30-70 30-20 50-20 50-25 49-25 49-26 48-26 48-27 47-27 47-30 46-30 46-33 45-33 45-43 44-43 44-44 43-44 43-48 42-48 42-49 41-49 41-50 40-50 40-52 39-52 39-54 37-54 37-55 38-55 38-56 39-56 39-57 38-57 38-59 37-59 37-61 38-61 38-64 43-64 43-67 42-67 42-68 44-68 44-67 45-67 45-69 44-69 44-70 43-70 43-75 44-75 44-77 45-77 45-79 46-79 46-81 52-81 52-82 54-82 54-83 56-83 56-85 57-85 57-86 56-86 56-89 57-89 57-92 59-92 59-94 55-94 55-99 54-99 54-101 53-101 53-102 52-102 52-105 53-105 53-107 54-107 54-108 56-108 56-109 57-109 57-111 58-111 58-113 59-113 59-117 58-117 58-121 57-121 57-123 56-123 56-125 55-125 55-128 56-128 56-131 57-131 57-133 58-133 58-134 59-134 59-136 63-136 63-130 64-130 64-127 65-127 65-125 67-125 67-124 68-124 68-125 69-125 69-127

Table 4. Parameters of the Generalized Travel-Time Curves (Depth = 0 km)
Basic Equation: $T\text{-}R/V_{red} = (A \pm \sigma_A) - (B \pm \sigma_B) \times R$

Phase	Range, km	V_{red}, km/sec	A	σ_A	B	σ_B	N	r	SD, sec
I. Platform areas									
Pn	220-1190	8.0	8.18	0.36	0.0049	0.0004	103	0.75	1.0
	1191-2200	8.0	12.49	0.49	0.0085	0.0003	262	0.88	1.3
Sn	220-2200	4.62	14.54	0.73	0.0043	0.0005	246	0.50	3.6
Pg	220-1400	6.0	-0.44	0.73	0.0047	0.0010	109	0.42	2.1
Lg	200-2500	3.5	-1.69	0.59	0.0020	0.0005	462	0.20	5.3
II. Paleozoic massifs and young plates									
Pn	200-2200	8.0	8.95	0.17	0.0047	0.0002	153	0.93	0.9
Sn	350-1400	4.62	14.40	0.70	0.0016	0.0007	100	0.24	2.7
Pg	220-1400	6.0	-0.44	0.73	0.0047	0.0010	109	0.42	2.1
Lg	200-2500	3.5	-1.69	0.59	0.0020	0.0005	462	0.20	5.3
III. Tectonic active regions									
Pn	200-1800	8.0	8.54	0.17	0.0024	0.0002	342	0.62	1.2
Sn	200-2000	4.62	13.18	0.57	-0.0018	0.0005	165	0.25	3.0
Pg	200-1400	6.0	-0.44	0.52	0.0026	0.0007	98	0.37	1.6
Lg	200-2500	3.5	-1.69	0.59	0.0020	0.0005	462	0.20	5.3

Note: **T - travel time, sec; R - epicentral distance, km; V_{red} - reduction velocity, km/sec; N - data set; r - correlation coefficient; SD - residual standard deviation, sec.**

Table 5. Modeling Errors for the Generalized Geotectonic Provinces of Northern Eurasia

Dis-tance, deg.	I. Platform areas				II. Paleozoic massifs and young plates				III. Tectonic active regions			
	Modeling Error, sec				Modeling Error, sec				Modeling Error, sec			
	Pn	Pg	Sn	Lg	Pn	Pg	Sn	Lg	Pn	Pg	Sn	Lg
2	0.6	1.4	0.4	3.4	0.5	1.4	2.6	3.4	0.9	1.2	2.7	3.4
3	0.6	1.2	0.3	3.2	0.5	1.2	2.1	3.2	1.0	1.4	2.9	3.2
4	0.8	1.8	2.3	3.3	0.8	1.8	2.0	3.3	0.9	1.3	2.4	3.3
5	0.8	2.2	2.1	3.7	0.8	2.2	2.0	3.7	0.9	1.3	2.0	3.7
6	0.8	2.4	1.9	3.8	0.8	2.4	2.2	3.8	1.2	1.3	2.3	3.8
7	1.0	2.7	2.8	3.9	0.9	2.7	2.7	3.9	1.2	1.6	2.7	3.9
8	1.5	2.2	2.9	4.1	0.9	2.2	2.9	4.1	1.2	2.0	3.6	4.1
9	1.2	2.1	3.3	5.6	1.0	2.1	3.1	5.6	1.4	2.0	3.8	5.6
10	1.2	3.0	3.4	5.3	1.0	3.0	1.7	5.3	1.3	2.0	3.4	5.3
11	1.3	2.8	3.3	5.1	1.0	2.8	2.8	5.1	1.3	1.9	4.2	5.1
12	1.3		3.8	6.7	0.9		4.1	6.7	1.2		4.4	6.7
13	1.3		3.7	6.3	1.2		3.4	6.3	1.3		3.2	6.3
14	1.3		3.4	6.4	1.1		3.2	6.4	1.4		3.1	6.4
15	1.4		4.2	6.4	0.9		3.5	6.4	1.2		3.1	6.4
16	1.3		4.5	6.4	1.0		3.4	6.4	1.5		4.4	6.4
17	1.4		3.9	6.3	0.9		3.5	6.3	1.5		3.1	6.3
18	1.3		3.4	5.7	0.9		3.3	5.7	1.5		2.3	5.7
19	1.3		3.5	5.3				5.3				5.3
20	1.1			6.2				6.2				6.2

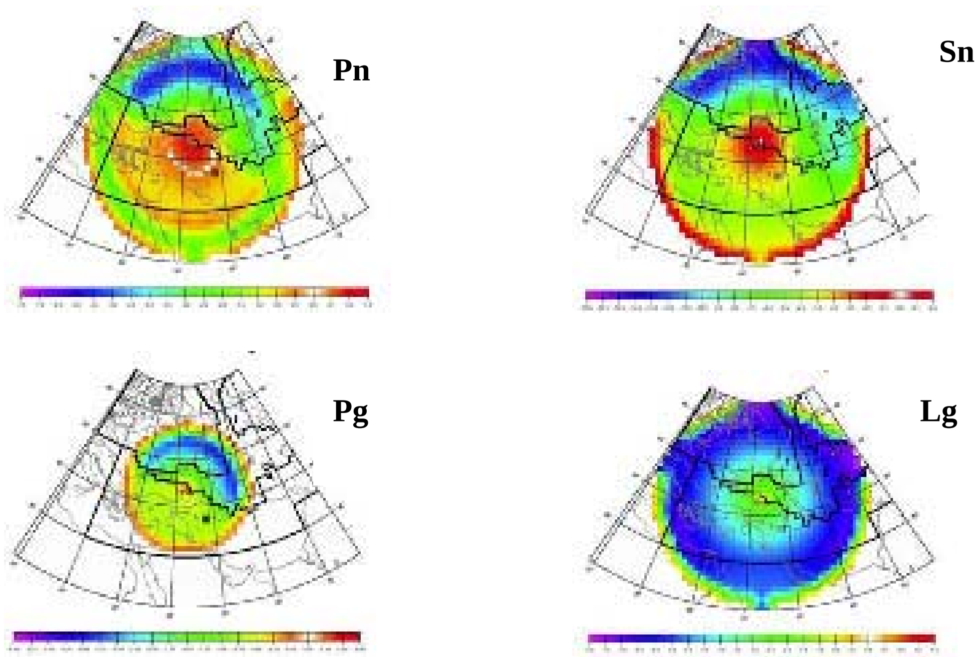


Figure 2. Examples of SSSCs for KIV0 developed using 1-D models.

Table 6. Travel-Time Residuals

IMS Station	Surrogate Station	Dist., km	Phase	N	IASPEI-91		1-D SSSCs	
					Mean, sec	SD, sec	Mean, sec	SD, sec
OBN	OBN	0.0	Pn	37	-3.1	1.6	0.7	1.1
			Sn	20	-11.7	4.0	-1.5	2.8
			Pg	13	-3.2	3.6	0.4	1.6
			Lg	17	-2.3	2.4	2.6	2.7
ARU	ARU	0.0	Pn	48	-3.3	1.7	0.2	1.2
			Sn	33	-7.2	4.8	0.6	4.2
			Pg	13	-3.4	2.3	-1.1	2.2
			Lg	24	-6.1	3.9	-2.0	5.7
KIV0	PYA	28.9	Pn	20	-2.6	1.4	-0.7	0.7
YAK	YAK	0.0	Pn	21	-3.6	2.5	0.0	1.5
			Sn	16	-12.4	5.7	-1.9	3.3
			Pg	6	-2.8	1.9	-0.3	1.9
			Lg	14	-2.8	4.2	2.2	4.1
TIXI	TIK	0.0	Pn	18	-4.0	1.3	0.3	1.3
			Sn	16	-10.8	4.3	-0.2	2.5
			Pg	4	-4.6	2.1	-2.2	2.0
			Lg	13	-2.5	3.4	2.4	3.6
TLY	IRK	75.9	Pn	22	-1.9	2.5	0.0	1.3
			Sn	15	-12.0	4.1	-3.2	3.0
			Pg	8	-1.7	1.2	1.1	1.0
			Lg	15	-3.2	3.9	2.4	3.1
MA2	MA1	0.0	Pn	10	-2.7	1.3	0.6	1.1

Table 7. Relocation Results for PNEs (GT0) Conducted in the Former USSR

No.	Date yy/mm/dd	Ndef (GAP)	IASPEI-91				SSSCs (1-D)			
			Mis-location, km	Ellipse area, km^2	To Res, s	GT within ellipse	Mis-location, km	Ellipse area, km^2	To Res, s	GT within ellipse
1.	69/09/02	18(120)	26.7	641	4.2	-	3.1	470	-0.6	+
2.	69/09/08	25(120)	33.3	397	3.5	-	7.9	360	-0.4	+
3.	69/09/69	14(106)	23.2	798	2.7	-	4.9	537	-0.1	+
4.	69/12/06	10(146)	59.6	798	0.2	-	4.4	572	1.4	+
5.	70/12/23	12(82)	9.1	648	1.9	+	13.8	435	-0.3	-
6.	71/07/02	18(129)	10.1	758	4.5	+	10.8	474	-0.4	+
7.	71/07/10	26(104)	10.3	625	4.2	+	15.8	407	-1.3	-
8.	71/09/19	20(143)	23.1	377	1.6	-	4.9	332	-0.6	+
9.	71/10/04	19(131)	12.2	430	3.5	-	5.8	335	-0.3	+
10.	72/08/20	17(103)	11.4	1156	3.4	+	9.5	500	-0.2	+
11.	72/09/21	14(132)	33.9	927	2.3	-	10.8	558	-0.8	+
12.	72/10/03	17(94)	30.1	781	2.9	-	10.5	461	1.2	+
13.	72/11/24_1	16(133)	16.1	650	-3.0	-	3.8	396	-0.9	+
14.	72/11/24_2	12(175)	4.4	1164	2.7	+	6.9	656	-1.2	+
15.	73/08/15	13(157)	21.4	1051	1.6	-	7.3	547	0.0	+
16.	73/08/28	12(153)	4.9	564	1.6	+	1.3	410	-0.5	+
17.	73/09/19	12(158)	26.7	1001	0.8	-	13.2	674	-1.3	+
18.	74/08/14	8(227)	45.4	3932	3.3	-	3.8	1952	1.4	+
19.	74/08/29	16(192)	35.7	1494	2.2	-	12.2	695	-0.2	+
20.	75/08/12	10(125)	41.7	1052	2.0	-	5.4	454	-0.8	+
21.	75/09/29	13(177)	48.8	713	2.9	-	12.6	1083	-0.4	+
22.	76/05/11	19(108)	17.2	426	4.3	-	5.4	345	-0.6	+
23.	77/07/26	13(210)	61.2	941	2.9	-	9.3	1196	-0.9	+
24.	77/08/10	12(218)	20.9	1571	-0.3	+	4.4	870	0.1	+
25.	77/08/20	18(120)	2.1	570	4.7	+	7.3	438	0.1	+
26.	77/09/10	16(156)	63.8	1198	2.5	-	19.4	576	-0.2	-
27.	77/09/30	12(206)	35.9	2597	2.6	-	6.6	1154	-1.9	+
28.	78/08/09	16(98)	17.2	679	2.5	-	7.3	379	0.4	+
29.	78/08/24	19(97)	30.5	451	4.9	-	14.0	379	0.5	-
30.	78/09/21	18(118)	56.2	419	4.3	-	10.6	363	0.0	+
31.	78/10/17_1	17(105)	23.4	667	3.3	-	5.8	348	-0.5	+
32.	78/10/17_2	17(119)	23.1	541	6.9	-	6.9	398	0.4	+
33.	79/08/12	16(94)	64.2	599	2.3	-	13.9	447	-0.1	+
34.	79/09/06	15(94)	2.9	594	4.9	+	3.8	435	0.2	+
35.	79/10/04	17(123)	10.3	580	3.7	+	6.2	463	0.3	+
36.	80/10/08	13(96)	23.1	939	4.5	-	7.0	481	1.1	+
37.	81/09/26_1	14(107)	27.4	895	3.1	-	10.5	473	-0.6	+
38.	83/07/10_1	16(132)	25.3	497	2.0	-	5.8	443	-1.2	+
39.	83/09/24_1	14(138)	20.0	983	3.7	-	10.1	544	1.1	+
40.	84/07/21_1	16(81)	9.8	609	3.7	+	6.9	393	0.1	+
41.	84/09/17	15(114)	51.3	935	2.7	-	14.6	472	-0.4	+
42.	85/07/18	17(104)	25.9	506	3.6	-	16.7	401	-1.3	-
43.	88/08/22	17(98)	27.7	355	4.3	-	7.6	418	0.4	+
44.	88/09/06	16(84)	5.4	379	4.7	+	8.5	327	0.5	+
Mean:			**26.6 km**	**861 km^2**	**3.0 sec**	**27%**	**8.6 km**	**547 km^2**	**-0.2 sec**	**89%**
SD:			**17.2 km**	**621 km^2**	**1.6 sec**		**4.0 km**	**298 km^2**	**0.8 sec**	